Surface Ozone Protocol

Purpose

To measure ozone concentrations at ground level

Overview

Students deploy a strip of paper that changes color in the presence of ozone. They use an ozone reader to determine the amount of ozone in ppb as indicated by the color change of the paper strip.

Student Outcomes

Students will learn to measure the concentrations of ground-level ozone in the atmosphere and to observe changes in the concentrations over time.

Science Concepts

Earth and Space Science

Weather can be described by quantitative measurements.

Weather changes from day to day and over the seasons.

Weather varies on local, regional, and global spatial scales.

The atmosphere is made up of different gases and aerosols.

Materials from human societies affect the chemical cycles of the Earth.

Geography

Human activities can modify the physical environment.

Atmospheric Enrichment

The concentration of surface ozone varies over time.

Cloud cover, air temperature, and wind direction affect ozone concentration.

Air quality is affected by the concentration of ozone present.

Scientific Inquiry Abilities

Use ozone strips and a strip reader to measure *in situ* ozone concentrations.

Use a weather vane to identify wind direction.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

Two five-minute time periods, one hour apart

Level

All

Frequency

Daily

Measurements starting within one hour of local solar noon are preferred.

Materials and Tools

Ozone Data Sheet

Clipboard

Pencil or pen

Chemical test strip in sealable plastic bag

Ozone Test Strip Scanner

Ozone Measurement Station

Device to measure wind direction

Clock or watch

Preparation

Assemble and install Ozone Monitoring Station.

Assemble or obtain and install Wind Direction Instrument.

Prerequisites

Cloud Protocols

Maximum, Minimum and Current Temperature Protocol

Welcome Introduction Protocols Learning Activities Appendix

Ozone Protocol – Introduction

Ozone is one of many gases in the air present in small amounts. These gases are called *trace gases*, and they play a role in the complex chemistry that determines the quality of the air we breathe. The amounts (concentrations) of these trace gases vary with time of day, from day to day, and from place to place. These variations are due to variations in the amounts of other gases from which trace gases are formed, and conditions such as air temperature. Monitoring the concentrations of trace gases is important for our understanding of air quality and how it is changing.

The oxygen molecule, consisting of two atoms of oxygen (O_2) (See Figure AT-SO-1) comprises 21% of Earth's atmosphere. Ozone, a molecule containing three oxygen atoms (O_3) (See Figure AT-SO-2) is present in much smaller amounts. Surface ozone can be produced when certain chemicals are released to the atmosphere and these chemicals react with each other in the presence of sunlight. Ozone is an important trace gas because it is very reactive, which means that it will easily 'stick' to, and react with all surfaces, including living tissue.

Ozone exists in both the stratosphere and troposphere; 90% of the ozone is found in the stratosphere, leaving a small amount in the troposphere. The ozone located in the stratosphere is often called 'good ozone' because it absorbs much of the sun's ultraviolet rays and protects the life forms on Earth. In contrast, the additional ozone that occurs in the troposphere is 'bad ozone' and is considered a pollutant. It is the main component of smog. Sometimes the term 'photochemical smog' is used, which is the correct term for pollution found near most urban areas. This type of smog is a product of chemical reactions in the atmosphere that take place only in the presence of sunlight.

Ozone is often one of the more abundant trace gases in the atmosphere and GLOBE students can measure it using simple chemical test strips. Collecting surface ozone data will provide a record of the amount of ground level ozone found in different geographic regions at different times. These data will help scientists understand how weather conditions influence the amount of ozone in the air. The GLOBE database will contribute valuable information for understanding how Earth's atmosphere may be changing.

Figure AT-SO-1: Oxygen Molecule

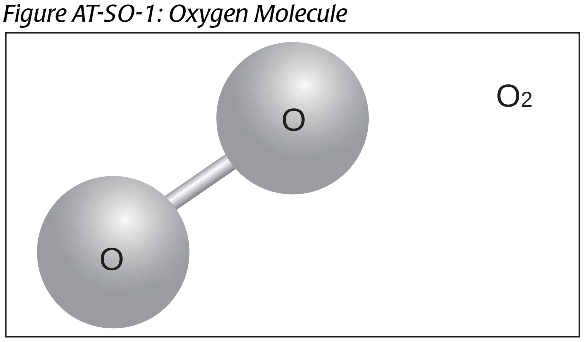
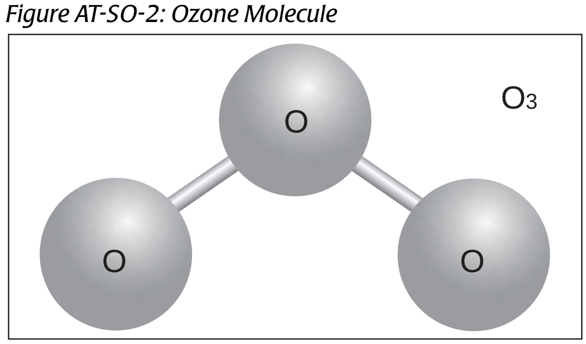


Figure AT-SO-2: Ozone Molecule



Teacher Support

The Measurement

The GLOBE surface ozone measurement is taken using a chemically sensitive strip that changes color in the presence of ozone. The more ozone present, the more change that will occur. The chemical strip is placed in the clip of the monitoring station preferably within one hour of local solar noon and left exposed to the air for one hour. It is then read using a scanner, which reads the strip more accurately and precisely than the eye, enhancing the scientific value of these data.

The amount of color change will increase if the strip is exposed to ozone for a longer period of time. Therefore, to ensure that GLOBE data are comparable around the world, the protocol specifies that the strip be exposed for only one hour and that the time it is exposed and the time it is read are reported to GLOBE to the nearest minute.

Placing the Chemical Strip

The chemical strip is exposed to outside air that is moving freely around the monitoring station. It is important to keep the strip in a closed plastic bag or pouch until it is placed in the monitoring station because once the strip is exposed it begins to react with any ozone that is present. When placing the strip, avoid touching the chemical on the strip to prevent contamination; however there is no danger should someone touch the strip.

Reading the Chemical Response

Reading of the chemically sensitive strip must be completed in the field. The team collecting the information records the level of response on the *Ozone Data Sheet*.

Determining the Level of Surface Ozone

The hand held scanner provides a more sensitive reading of the color of the ozone test strip than can be achieved with the naked eye. The scanner is designed to give a reading of ozone concentration in units of parts per billion. The correspondence between the color of the strip and the average concentration of ozone in the air during the time the strip was exposed assumes that the exposure was for just one hour.

Place the chemical strip into the thin slot on top of the scanner. Hold the edge of the chemical strip on the end with the words "Test Card". The chemical side of the strip should face the display. Gently slide the strip into the slot on top of the scanner until the bottom of the strip touches the base of the scanner and won't slide in any further. This places the circle with the chemical in the center of the end of the scanner. It will take a few seconds for the scanner to read the color change of the strip, and identify the ozone concentration in parts per billion.

Measurement Logistics

The need to expose the ozone strip for one hour may pose a logistical challenge. One approach to solve this is to expose the ozone strip at the same time that the daily atmosphere measurements of maximum, minimum, and current temperature, precipitation, relative humidity, and clouds are made within one hour of local solar noon. These measurements will then provide one set of the cloud and current temperature measurements required to support the ozone measurement. Students would also read wind direction at this time.

Just a few minutes before an hour has passed students need to go to the site to measure the concentration of ozone detected by the strip. At the same time, they will need to open the instrument shelter and read the current temperature, do the *Cloud Cover* and *Cloud Type Protocols*, and again observe the wind direction. Unusual weather conditions that may have affected the response of the strip are reported as comments or metadata. The students who read the ozone strip do not have to be the same students who exposed the strip. This gives you some flexibility to work within the constraints of the school day and student schedules.

The key to this two time measurement is to establish a clear schedule so that everyone involved knows what they are expected to do and when to do it. Design a system so students know when the hour is nearly finished, and return to the site to read and record the data.

Ozone concentrations often vary over the day. To build a consistent set of ozone readings that can be compared across many schools, the primary data set desired is of measurements for a one hour period that begins within one hour of local solar noon. This should require the least effort as noted above. If this timing will not work at your school or if you wish to take more than one ozone measurement a day, you may do this protocol at other times. These data may not be displayed on GLOBE visualizations of mid-day ozone values, but they will be included in the tables of data associated with your school and will be made available in graphs. The key is that the ozone strip is exposed for one hour and that clouds, current temperature, and wind direction are reported for both the beginning and end of this time period.

Scanner Use and Care

An ozone measuring hand-held scanner is used to measure the level of ozone present in the atmosphere. It is important to read the handheld scanner in a shaded area with the scanner placed on a level stable surface. Sunlight and motion can affect the scanner reading.

Placing the scanner inside the instrument shelter provides the level shaded surface needed to take the ozone measurement. The instrument should be inside the GLOBE Instrument Shelter for 5 minutes to allow it time to adjust to the outside conditions. During these 5 minutes, students should be recording cloud cover, temperature, and wind direction data. After recording these data, the students will return to the instrument shelter, turn on the scanner, and wait 1 minute to allow the internal electronics to stabilize. The scanner will automatically turn off. Turn it back on immediately to calibrate the unexposed ozone test strip. These same steps should be repeated when the students return to the site to read the exposed ozone test strip. The scanner must be brought back into the classroom after calibrating the unexposed strip as well as after reading the exposed strip.

The ozone measuring hand-held scanner is a rugged instrument, but care must be taken to ensure accurate measurements.

1. Keep the scanner at room temperature and in its protective case to protect it from dirt and dust when it is not in use.
2. Go to RESET and reset the scanner each day to MODE 01
3. When the scanner is turned on to calibrate the unexposed strip or read the exposed strip, be careful not to accidentally touch or bump the two buttons on the edge of the scanner. If the buttons are touched without a strip in the scanner, the scanner will respond by trying to save a reading without a strip and you will not have an accurate ppb reading. The scanner will need to be recalibrated with an unexposed strip to reset the white paper reading.
4. The test strip scanner is sensitive to temperature changes. If the outside temperature is not within 5° C of the classroom temperature, the scanner should remain inside and the exposed strip should be brought back into the classroom to be read. The time it takes to bring the ozone strip from the monitoring station to the classroom will not significantly impact the ozone concentrations.
5. Turn the scanner off when it is not in use.
6. Do not drop the scanner.
7. Protect the scanner's electronics from water.
8. Change the three AAA batteries when the scanner indicates they have low power.

Supporting Measurements

Since the chemistry of trace gases in the atmosphere depends on the amount of sunlight present, students are asked to record the cloud cover and type when they expose the strip and when they read it. Many chemical reactions also depend on temperature and so students are asked to measure current temperature when the strip is exposed and read. Lastly, the amounts of trace gases present may vary considerably depending on what is upwind from your measurement site. Students also measure the wind direction at the beginning and end of the exposure period.

These supporting data can be compared to data collected from other schools in different locations. As students learn about the air they breathe, they should explore how weather conditions can affect the amount of ozone in the air around them. Comparing the data they gather with students from other regions of the world is an appropriate topic for student inquiry.

Note: If wind measurements are not available, data from the closest surface weather site (available on the Web) would be important to have in the analysis of the data (as well as for the analysis of other atmosphere protocol measurements). If data are taken from the Web, this fact should be noted in the metadata

Student Preparation.

Students need to be trained how to measure and record the surface ozone level. It will be important to the accuracy of the measurement that students are able to:

1. Work in cooperative groups of 2-4 students to gather, analyze, and discuss results.
2. Organize all materials needed to set up and take the measurement of surface ozone.
3. Follow a schedule to return to the ozone monitoring site 5-10 minutes before strip is to be read to take supporting measurements.
4. Identify and record the starting time when they expose the chemical strip, and accurately read the strip at the end of one hour.
5. Carry the chemically sensitive strip to the monitoring site in a plastic bag to control exposure time.
6. Read and follow the *Ozone Field Guide* instructions for placing and reading the ozone strip.
7. Read the current temperature from the maximum/minimum thermometer without altering the maximum and minimum settings.
8. Identify and record cloud type and cover using the *Cloud Protocols*.
9. Record data accurately and completely for reporting to GLOBE and for future graphing and analysis.
10. Record their observations in their individual GLOBE Science Logs.
11. Respond in their GLOBE Science Logs to a question that reveals the individual nature of their learning experience, share their responses with their team, discuss, and choose to add to their response as a result of their discussion without changing their original response.

Helpful Hints

Have a designated area to keep the clipboard with the *Data Sheet* to facilitate different teams working to record data. Keep the *Data Sheets* in a notebook so that they are not misplaced.

From time to time check the written record in the Data Book to ensure that it is complete and accurate.

Sometimes a chemical strip gets damaged while exposed to ambient air. If the chemical strip gets wet, the response will be marbled. Enter M for data for this day or time period. This will indicate that the measurement was taken, but it was contaminated.

If there is no response on the chemical strip, enter 0 to indicate no surface ozone is present.

Questions for Further Investigation

Is the amount of ozone you observe related to other atmosphere phenomena? Which ones? How?

How can you use your data collected over a period of time to predict future changes in the atmosphere?

What is the variability of ozone in the atmosphere daily? Seasonally? Annually?

Exposing the Ozone Test Strip

Field Guide

Task

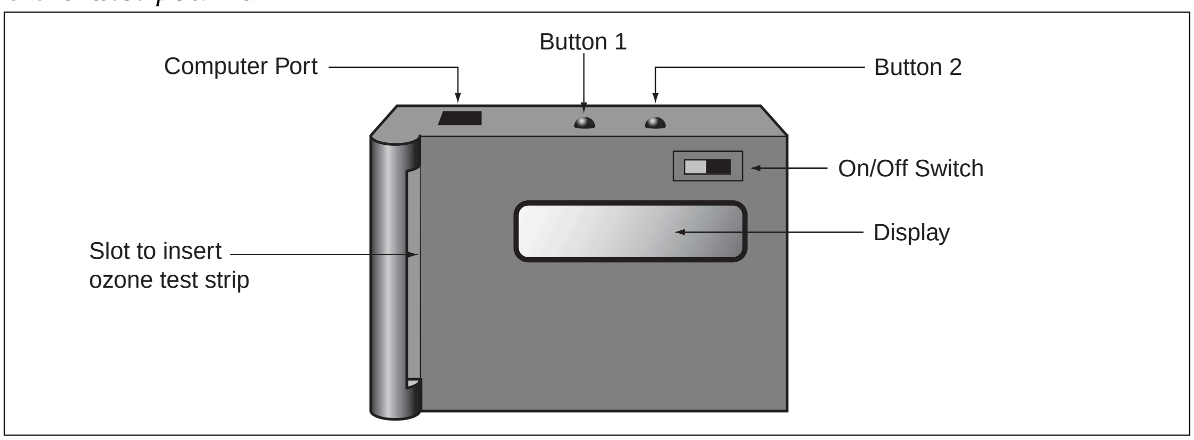
Begin the measurement of surface ozone concentration.

Record cloud conditions, wind direction, and current atmosphere temperature.

What You Need

- ❑ One Ozone Test Strip
- ❑ Plastic bag to carry the test strip to your site
- ❑ Ozone Test Strip Scanner
- ❑ Clipboard
- ❑ *Ozone Data Sheet*
- ❑ Pen or pencil
- ❑ *Measuring Wind Direction Field Guide*
- ❑ *Cloud Cover Field Guide*
- ❑ *Cloud Type Field Guide*
- ❑ GLOBE Cloud Chart
- ❑ Wind Direction Instrument
- ❑ Key to your instrument shelter
- ❑ A clock or watch accurate to the nearest minute

Ozone Test Strip Scanner



In the Field or Classroom

1. Fill out the top of the *Ozone Data Sheet.*

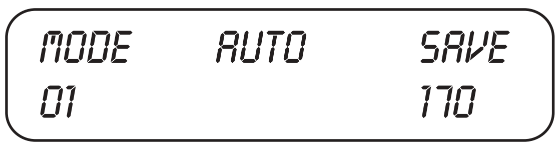
2. Remove a single ozone test strip from the plastic bag,

3. Record the date and starting time.

Calibrating the Scanner

4. Place the scanner on a steady surface out of direct sunlight.

5. Turn on the scanner and you should see the following in the LCD readout.
(The number you see under SAVE may be different.)



6. Place the unexposed ozone test strip into the scanner with the **chemical side facing toward the display.**

7. Press button 1 until you see CALIB on the display.

8. Press button 2 to select WHT PAPER.
The number under EXIT may fluctuate. This is ok.

9. Hold down buttons 1 and 2 simultaneously to save the calibration. The scanner will return to Mode 01. (The reading under SAVE should read 000 and may fluctuate. If it reads higher than 003, repeat steps 7 – 9 to recalibrate the instrument.)

10. Remove the unexposed strip. Turn off the scanner.

In the Field

11. Place this ozone test strip in the clip on the monitoring station. Do not touch the chemical part of the strip at any time. (It is not harmful to you, but touching it may prevent you from getting an accurate measurement.) Record the time.

12. Determine cloud cover and cloud type following the *Cloud Cover* and *Cloud Type Protocols.*

13. Measure and record the current temperature on the thermometer in your instrument shelter (to the nearest 0.5° C).

14. Record the wind direction.

Reading the Ozone Test Strip

Field Guide

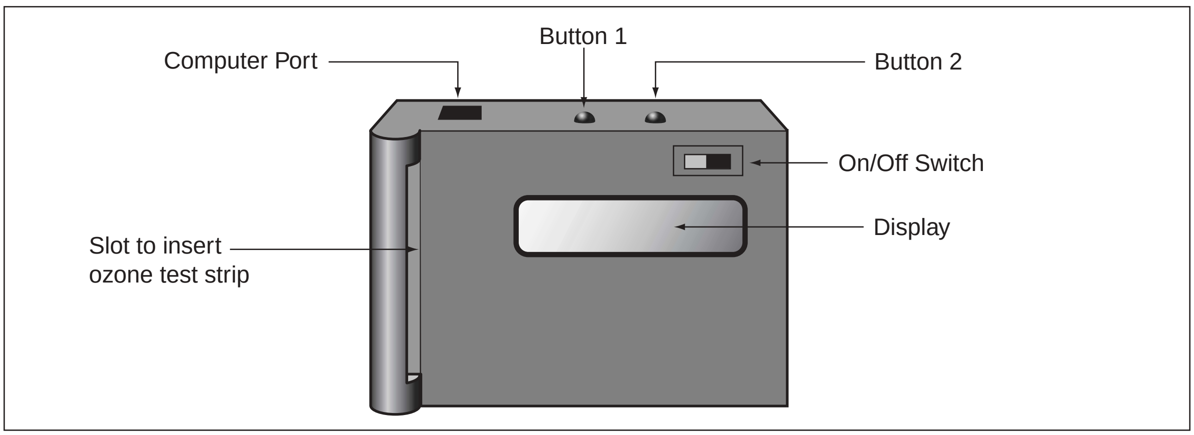
Task

Complete the measurement of surface ozone concentration after the ozone test strip has been exposed for one hour.

Record cloud conditions, wind direction, and current atmosphere temperature.

What You Need

- ❑ Ozone Test Strip Scanner
- ❑ Clipboard
- ❑ *Ozone Data Sheet*
- ❑ Pen or pencil
- ❑ GLOBE Cloud Chart
- ❑ *Cloud Cover Field Guide*
- ❑ *Cloud Type Field Guide*
- ❑ *Measuring Wind Direction Field Guide*
- ❑ Wind Direction Instrument
- ❑ Key to your instrument shelter
- ❑ A clock or watch accurate to the nearest minute



In the Field

Ten minutes before the ozone strip has been exposed for one hour:

1. Determine cloud cover and cloud type following the *Cloud Cover* and *Cloud Type Protocols*.

2. Read and record the current temperature on the thermometer.

3. Determine and record the wind direction.

After the ozone strip has been exposed for one hour:

4. Remove the test strip from the clip; be careful not to touch the chemical part of the strip.

In the Field or Classroom

5. Turn on the scanner. You should see something like the following display:

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MODE      AUTO      SAVE
01                  170
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6. Slide the strip into the slot on top of the scanner until the bottom of the strip touches the base of the scanner and won't slide in any further. The chemical part of the strip should face the display and be in the center of the end of the scanner.

7. Place the scanner on a stable surface out of direct sunlight. The reading should stop fluctuating after 5-10 seconds. If it fluctuates between two numbers, choose the lower of the two readings after the test paper has been in the scanner for 10-15 seconds.

8. Record the ppb reading on your *Data Sheet.*

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9. Record the time you read the ozone strip.

   Note: It is not uncommon for the scanner to display more than one value. Because of the nature of the electronics in the scanner and the fact that the color on the exposed strip is rarely completely uniform (although it may appear that way to the naked eye), it is most common that the concentration shown in the display fluctuates among several values and eventually starts to increase the longer the strip remains in the unit. Because the measurement accuracy is 10 ppb, fluctuating numbers within a range of 1-5 ppb are acceptable. The goal of the surface ozone measurement protocol is to be able to distinguish between values that are regarded as low (0-20 ppb), normal (30-50 ppb) and high (>60 ppb).

Measuring Wind Direction
Field Guide

Task
Determine wind direction using Wind Direction Instrument.

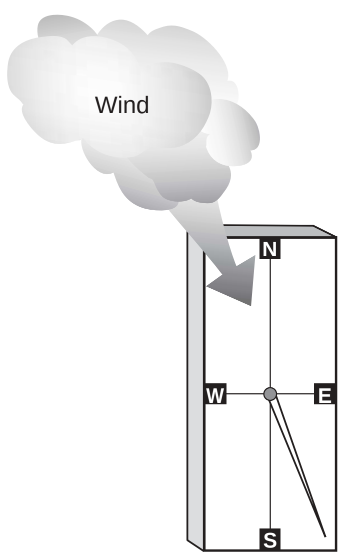
What You Need
- ❑ Wind Direction Instrument
- ❑ Clipboard
- ❑ *Ozone Data Sheet*

In the Field
1. Place your wind direction instrument on a table or bench so that it is about 1 meter off the ground.
2. Use the compass to find magnetic north and align the base of your model marked N to match true north.
3. Look at the wind sail to see if there is any wind blowing.
4. Put your right hand on your hip and your left arm out straight.
5. Turn your body so that your straight arm is pointing in the same direction as the wind sail. Your right elbow is now pointing in the direction of the wind.
6. Record this direction on your *Data Sheet*.

For example, if your wind sail is pointing south, your straight arm should be pointing south. In order for the wind sail to be pointing south, where does the wind have to be coming from? North.

Your straight arm is pointing where the wind is going, and the elbow of your bent arm is pointing in the direction where the wind is coming from, north. Winds are identified by the direction from which they are coming.

Wind is coming from the **northwest**



Wind sail is being blown towards **southeast.**

Frequently Asked Questions

1. What if the ozone strip does not change color after one hour?

If there is no color change, enter 0 on the data sheet, because it indicates that there is very little or no surface ozone present.

2. What if the ozone strip got wet due to rain or snow and the color is marbled, or the surface is not one complete color?

Your ozone measurement strip is contaminated or spoiled which means the data are not accurate. Report your data as M to the GLOBE Data Server. Note as a comment weather conditions which may have affected your results. Still measure the current temperature, cloud cover and cloud type and report them.

3. We are not in school on the weekend, how can we collect data?

Persistence in data collection is important, so work with your GLOBE team to arrange for a volunteer to bring one or two students to your Atmosphere Study Site on weekends and holidays if possible. Data from school days alone are still valuable, but for some schools weekends will have systematically different ozone levels.

4. Can the plastic disk and strip be placed on the weather station?

No. They should be on different posts.

5. Why is it important to take the temperature reading after recording the ozone level?

The strip will continue to respond to the gases in the air. So it is important to take the ozone reading and then the temperature reading.

6. Why is it important to record the wind direction, cloud cover and type, and current temperature before calibrating an unexposed strip or reading the exposed strip?

The scanner needs time to adjust to the outside conditions. If you return to the monitoring site 5-8 minutes before the hour you have to read the exposed strip, you can place the scanner in the instrument shelter, and record the cloud cover and type, wind direction, and current temperature reading while the scanner adjusts to the outside conditions. Remember that the strip will continue to respond to the gases in the air and it is important to read the response of the strip one hour after it was placed.

7. What are some common problems with using the test strip scanner and how can I fix them?

Problem 1: I don't know if my scanner is calibrated correctly

To check the calibration of the scanner, first turn the scanner on and reset it. Go to CALIB and place an unexposed strip in the Scanner. Push the right button, button #2, and let the scanner read the unexposed strip for 1 minute. Record the lowest and highest readings. A large range (> 5 ppb) between the lowest and highest readings, or a reading of 180 or higher indicates a scanner problem. Contact the Vender and return the scanner for repairs.

Problem 2: The reading under "SAVE" is a Range of Low Fluctuating Numbers

The scanner was calibrated without an unexposed strip. Push the left button, button #1, until CALIB shows on the LCD. Place an unexposed strip in the scanner, push the right button, button #2, and then hold both buttons down simultaneously to reset the calibration for an unexposed strip. The scanner should return to SAVE 170.

Problem 3: The LCD Reads 8HR PPB or AQI When the Scanner is Turned On

If settings have been changed the reading under SAVE will also be different. Someone has changed the SETTING categories in the scanner. Push the left button, button number 1 until SETTINGS appear on the LCD. Push the right button, button #2, and you will see DRATION = 8HR. Push the right button until you see DRATION = 1HR. Push the left button and it will show MEASURE = AQI. Push the right button until it scrolls to MEASURE = PPB and push the left button. Now push both buttons simultaneously to save the settings and return to the original screen on the LCD. It should read:

MODE	AUTO	SAVE
01	1HR PPB	170

Surface Ozone Measurement - Looking at the Data

Are the data reasonable?

Average surface ozone measurements can range from nearly 0 ppb to over 150 ppb (and even 200 ppb in extremely polluted conditions). Research has shown that different areas experience different levels of surface ozone depending upon time of year, location, and the level of hydrocarbons and nitrogen oxides in the air, since they are the precursors needed to produce ozone near Earth's surface.

Students taking daily measurements over several weeks should observe a range of ozone levels. Often, there is a gradual build-up over several days, and then concentrations drop over a shorter period of time. Students should take particular note of the wind direction and temperature over this several-week period along with the passage of weather fronts. Has the wind shifted? Are there days when there is a heavy overcast and the ozone levels show unusually low values? On a longer time scale, how do surface ozone measurements vary with season and from one year to another? Gaining experience with the variations in ozone concentration at your own site is the best way to judge whether individual measurements are reasonable.

Although surface ozone concentrations can be quite variable, there are some correlations that usually apply. Sunlight drives some of the chemical reactions in the atmosphere which lead to the formation of ozone. Therefore, it is reasonable to expect higher surface ozone concentrations in the summer than in the winter. In low latitudes, where the amount of sunlight is relatively constant (and high) throughout the year, highest surface ozone values are found most often if there is a seasonal source of the precursors needed to generate ozone. Thus, in many tropical areas, surface ozone levels will likely increase if there is a preferred time of the year when biomass burning takes place. This seasonality may be linked to the region's dry season, since it is easier to burn vegetation after it has dried out over a period of several weeks.

On shorter time scales, heavy cloud cover and low surface ozone concentrations are often observed at the same time. It is unlikely that high concentrations would be present if it is raining. When there is little or no wind, local concentrations of the chemicals leading to ozone formation can build up. Under these conditions, the ozone formed locally is not carried away and is not diluted with air from higher in the troposphere where ozone concentrations are generally lower. The chemical processes leading to ozone production happen more rapidly under warmer conditions.

What do people look for in these data?

Monthly data gathered at fixed times

One method of collecting data is to measure ozone every day for a specific period of time, usually for at least one month, and hopefully longer. An example of a 1-month data record is presented in Table AT-SO-1.

This is a typical data set that would be gathered by students at the same time every day. Plotting ozone concentration versus temperature does not reveal any strong correlation; for example, both the warmest day (11/1) and the coldest day (11/23) have the two highest ozone readings (55 and 46 ppb). There is, however, a general tendency for concentrations to be lower when the temperatures are colder: From the 10^{th} through the 25^{th}, temperatures are below 20˚ C and the ozone concentrations average 15 ppb. When the temperatures are >20˚ C *and* it is not raining, the average concentration is 38 ppb., more than twice as high as when it is relatively cool. The other very important factor in this analysis is the wind direction. When the wind is from the south or southwest, the average concentration is 41 ppb. For this particular data set, the wind direction appears to be the primary factor signaling higher concentrations. The reasons for this finding may be simple, or they may be complex. For example, is there a large metropolitan area located nearby and when the air is from the south, are you downwind of a large pollution source? Such an effect is often observed in the Los Angeles basin where highest concentrations of ozone are primarily found in the suburban areas downwind from the

Table AT-SO-1 ***Heart of Mary School–ppb Ozone and Metadata***

Date	ppb	Ending Temp	End Time	Cloud Type	Cloud Cover	Wind Direction (beginning/ ending)	Notes
11/1/00	55	28	12:50	Cirrostratus, Cumulonimbus	Broken	SW/SW	
11/7/00	19	26	12:30	Stratocumulus	Overcast	SW/SW	Heavy rain
11/8/00	12	26	12:25	Stratocumulus	Overcast	SE/SE	Light rain
11/9/00	35	24	12:25	None	No clouds	NW/NW	
11/10/00	13	14	12:15	None	No clouds	NW/NW	
11/11/00	15	16	12:25	None	No clouds	W/NW	
11/14/00	22	14	12:30	Cirrus	Scattered	NW/NW	
11/15/00	16	14	12:30	Cirrostratus	Scattered	NW/NW	
11/17/00	13	5	12:30	Cirrostratus	Overcast	NW/NW	31 mm of rain
11/20/00	14	14	12:40	None	No clouds	NW/NW	
11/21/00	13	9	12:25	None	No clouds	NW/NW	
11/22/00	16	12	12:45	Cirrostratus	Clear	NW/NW	
11/23/00	46	6	12:15	Nimbostratus	Overcast	S/S	
11/25/00	16	15	1:00	Nimbostratus	Overcast	W/W	
11/27/00	31	21	12:30	None	No clouds	SW/SW	
11/28/00	30	20	12:40	Cirrus	Overcast	SW/SW	
11/29/00	40	21	12:30	Cumulus	Clear	W/W	

metropolitan area. Another reason may be due to the placement of the ozone monitoring site if, for example, there is an open field to the south and a forested region to the north. Ozone is destroyed as it comes in contact with leaves on a tree, so a fetch of air from the north in this case could be lowering the amount of ozone observed at the monitoring site. In this particular example, the metadata are extremely important for data interpretation.

An Example of a Student Research Investigation

Forming a Hypothesis

A student of Heart of Mary School in Alabama has decided to focus on the interconnections of atmospheric conditions on the level of surface ozone observed. She has decided to begin her research process by looking at the visualizations of measurements of the ozone level and current temperature at her school for the month of April. Her initial hypothesis is *the level of surface ozone produced is directly related to the current temperature.*

Collecting and Analyzing Data

Measuring surface ozone is a new protocol, but her school has several months of data they have gathered during the initial implementation of the new protocol. She decides to identify a month that is beginning to show increased levels of ozone to begin her analysis. There is an Air Quality Monitoring site near her school, which has been turned

Welcome Introduction Protocols Learning Activities Appendix on since March, so she accesses the ozone levels measured by the professional equipment to be sure the data she has collected are of good quality. She finds her data fall within a range of ±10 ppb of the professional readings. Clearly, her data are good enough for her project.

She begins by organizing a spreadsheet of her ozone measurements, ending temperature, cloud type and cover, and the starting and ending wind direction by the dates the information was recorded. See Table AT-SO-3.

She generates a plot of the ozone measurements and considers measurements of 39 ppb and lower as low ozone levels and 60 ppb and higher relatively high ozone. She then graphs the ozone and current temperature measurements. See Figure AT-SO-3.

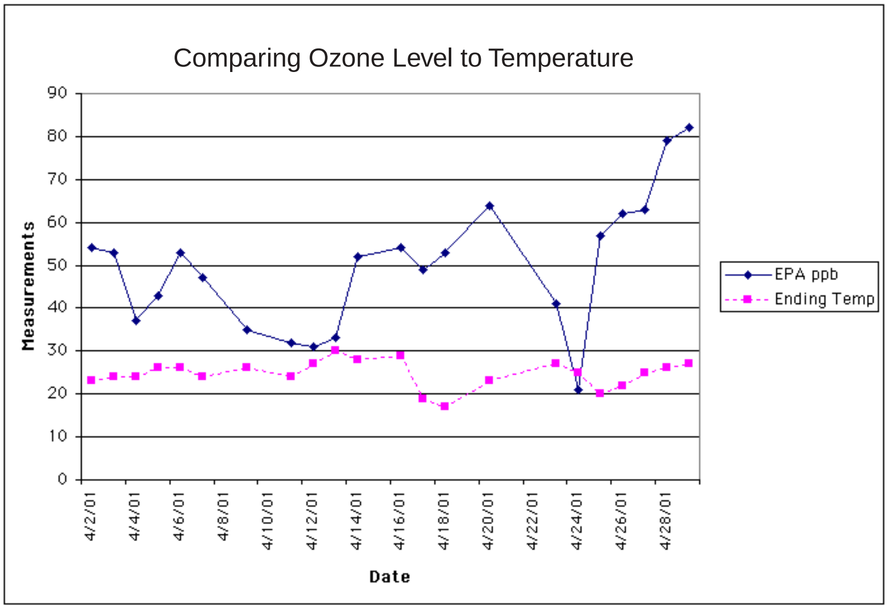
While reviewing her data she realizes that there is a pattern on some days when the temperature goes up, the ozone level increases, and when it goes down the ozone level decreases. However, there are days when the temperature was equally high and the ozone level dropped dramatically. She

Heart of Mary School Ozone Measurement Levels and Metadata

Table AT-SO-2 *Taken at 17:30 UT Time*

Date	ppb	Ending Temp	Cloud Type	Cloud Cover	Wind Direction (beginning/ending)
4/2/01	54	23	Cirrus	Broken	SW/SW
4/3/01	53	24	Stratocumulus	Broken	NW/NW
4/4/01	37	24	Stratocumulus	Overcast	NW/NW
4/5/01	43	26	Cirrostratus	Broken	NW/NW
4/6/01	53	26	Cirrostratus	Broken	N/N
4/7/01	47	24	Cirrostratus	Broken	NE/NE
4/9/01	35	26	Cumulus	Broken	SW/SW
4/11/01	32	24	Altostratus	Broken	SW/SW
4/12/01	31	27	Cirrus	Scattered	SW/SW
4/13/01	33	30	Altocumulus, Cumulus	Broken	SW/SW
4/14/01	52	28	Cirrostratus, Cumulus	Broken	W/W
4/16/01	54	29	Altostratus,Cirrocumulus	Clear	NW/NW
4/17/01	49	19	None	Clear	N/N
4/18/01	53	17	None	Clear	N/N
4/20/01	64	23	None	Clear	S/SW
4/23/01	41	27	None	Clear	SW/SW
4/24/01	21	25	Cumululonimbus, Stratocumulus	Overcast	SW/SW
4/25/01	57	20	None	Clear	NW/NW
4/26/01	62	22	None	Clear	N/N
4/27/01	63	25	None	Clear	NW/NW
4/28/01	79	26	None	Clear	W/SE
4/29/01	82	27	Cirrus, Altostratus, Cirrocumulus	Broken	W/SE

Figure AT-SO-3



knows her data are reasonable as she compared them with professional data, and wonders if she reorganizes her data by temperature will she be able to quickly identify the days with similar temperature that have different ozone levels. This might enable her to identify other factors influencing the level of ozone produced. See Table AT-SO-4.

She realizes that with clear conditions and an increase in temperature, the level of ozone is higher except for one day. Another observation she makes is that the presence of clouds influences the level of ozone observed regardless of the temperature, and on days with roughly the same temperature those with overcast sky conditions have lower levels of ozone. The general pattern of increasing temperatures with broken clouds still provides an increase in the level of ozone produced except for a couple of days when the temperature was high, few clouds, but the level of ozone was lower than similar days. The wind direction was different indicating that perhaps wind direction may influence the level of ozone. The wind directions at the beginning and ending of the observation periods are usually the same during this month except the two data points taken on April 28 and 29.

Further Analysis

Students could go a step further and determine the ratio of levels of ozone days by identifying patterns of ozone levels. Students would be able to determine whether or not the number of high ozone days is increasing or decreasing each month. The categories organized to calculate ratio might be: low levels of 39 ppb or lower, 40-49 ppb, 50-59 ppb, 60-69 ppb, 70-79 ppb and 80 ppb and higher. The following sample of ozone data from March through June demonstrates how ratio may be used to analyze monthly ozone patterns. See Table AT-SO-4.

At a glance the student can visually see patterns developing from March through June and also recognize the impact of inconsistent data upon their ability to accurately analyze changes occurring over time. They might relate this to problems scientists have with incomplete data records. She will observe that there are consistently days with low levels of ozone, but she can see that the levels of ozone are increasing each month. Upon realizing that June is not a complete data summary, she might question how missing data will impact any conclusions that might be made from the review of June's data.

By reviewing the percentages for each category of ozone level, she will see the continuous increase in ozone levels and identify the general variability of ozone levels for a given period of time. See Table AT-SO-5. June's record demonstrates a void in the data, which makes it difficult to draw accurate conclusions.

Table AT-SO-3 ***Heart of Mary School Ozone Measurements April 2001***

Temp.	ppb ozone	Cloud Type	Cloud Cover	Wind Direction
17	53	none	Clear	N/N
19	49	none	Clear	N/N
20	57	none	Clear	NW/NW
22	62	none	Clear	N/N
23	64	none	Clear	S/SW
23	54	Cirrus	Broken	SW/SW
24	53	Stratocumulus	Broken	NW/NW
24	47	Cirrostratus	Broken	NE/NE
24	37	Stratocumulus	Overcast	NW/NW
24	32	Altostratus	Broken	SW/SW
25	63	none	Clear	NW/NW
25	21	Cumululonimbus, Stratocumulus	Overcast	SW/SW
26	79	none	Clear	W/SE
26	53	Cirrostratus	Broken	N/N
26	43	Cirrostratus	Broken	NW/NW
26	35	Cumulus	Broken	SW/SW
27	82	Cirrus, Altostratus, Cirrocumulus	Broken	W/SE
27	41	none	Clear	SW/SW
27	31	Cirrus	Scattered	SW/SW
28	52	Cirrostatus, Cumulus	Broken	W/W
29	54	Altostratus, Cirrocumulus	Clear	NW/NW
30	33	Altocumulus, Cumulus	Broken	SW/SW

Future Research

Another question raised by the student is how she might be able to identify a monthly pattern for ozone levels. She wonders if she calculates the temperature and ozone mean, for the four months, if the means will reflect a continuous increase or decrease in the level of ozone measured. Can a monthly ozone mean calculated for each month of the year provide information about the pattern of ozone levels? How do the patterns of ozone levels relate to seasonal changes during the year?

Identifying the ozone pattern in her area will provide insight into atmospheric conditions that influence ozone levels. Exploring the relationship between wind direction patterns and levels of ozone measured provides a different challenge, but can be very exciting. Using the GLOBE database, the student may choose another school in a town located approximately at the same latitude, but in a different geographic region to determine what other variables might influence the level of surface ozone produced. Posing and addressing additional questions is easier when GLOBE schools consistently report data. As demonstrated in this study, missing data makes it difficult to monitor how the atmosphere changes over time.

Heart of Mary School-Observed Ozone Levels (ppb)
March through June

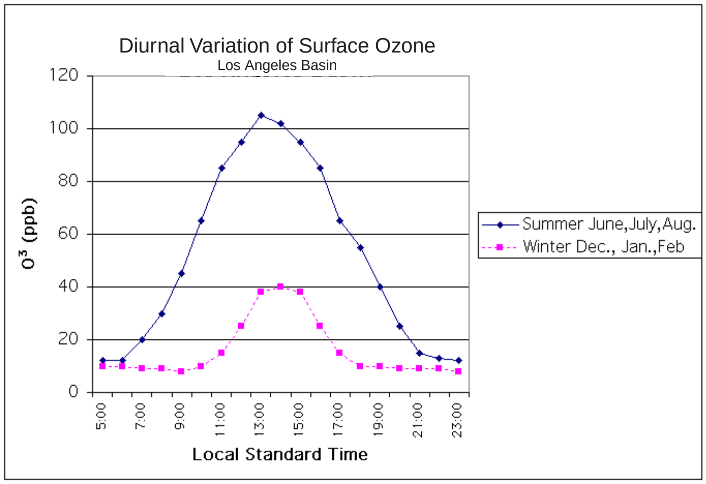
Table AT-SO-4 *Grouped by Category (level) of Ozone Concentration*

	March	April	May	June
	17	21	35	28
	24	31	37	25
	33	32	45	26
	33	33	46	30
	34	35	49	31
	36	37	50	40
	36	41	54	55
	40	43	56	67
	41	47	56	70
	41	49	57	76
	42	52	57	78
	44	53	58	87
	44	53	58	87
	45	53	59	88
	47	54	60	95
	47	54	62	
	48	57	63	
	50	62	66	
	56	63	66	
	60	64	69	
	74	79	71	
	74	82	74	
			74	
			74	
			86	
Days	**22**	**22**	**25**	**15**

Table AT-SO-5 ***Ratio of Ozone Levels for Four Months***

Month	March		April		May		June	
Total Number of Days with Ozone Measurements	22		22		25		15	
Category	Ratio	%	Ratio	%	Ratio	%	Ratio	%
< 40 ppb	7:22	32%	6:22	27%	2:25	8%	5:15	34%
40 – 49 ppb	10:22	45%	4:22	18%	3:25	12%	1:15	7%
50 – 59 ppb	2:22	9%	7:22	32%	9:25	36%	1:15	7%
60 – 69 ppb	1:22	5%	3:22	16%	6:25	24%	1:15	7%
70 – 79 ppb	2:22	9%	1:22	5%	4:25	16%	3:15	20%
> 80 ppb	0:22	0%	1:22	5%	1:25	4%	4:15	27%

Figure AT-SO-4



Studying Diurnal Variation of Surface Ozone and Validation of Data

Students may also want to investigate the diurnal variation of surface ozone. A typical set of diurnal ozone is shown in Figure AT-SO-4 for the Los Angeles basin. The two curves represent summertime (dashed line) and wintertime (solid line) concentrations plotted as a function of local time. From the difference in amplitude on the two curves, it is easy to see why the data set gathered by students would likely be more interesting in the summer, late spring or early autumn rather than in the middle of winter when lower ozone concentrations and less variability would be expected

Table AT-SO-6 summarizes two days of surface ozone measurements during times of when students would be available to take such measurements. This particular set of data was obtained at an operational EPA monitoring site so that the student measurements could be compared directly with the measurements using a calibrated ozone monitor that cost thousands of dollars. This is one comparison that has allowed GLOBE to determine the how well its measurement system performs in the field.

The goal of the surface ozone protocol is to obtain ozone concentrations with an accuracy of 10 ppb or better. From the data shown in Table AT-SO-6, we can see that the accuracy goal has been achieved in this test. On both days, the Zikua system showed higher concentrations in the afternoon although the diurnal difference was much greater on the second day. The EPA monitor confirmed the diurnal behavior and also measured a greater difference between the afternoon and morning of the 30th.

Therefore, another check on the reasonableness of data from a single day is to compare it with data from other near-by GLOBE schools or other sources of surface ozone data. Is there a reasonable explanation for the differences you see?

Table AT-SO-6

Date	Start Time	GLOBE Reading (ppb)	EPA Reading (ppB)
8/29/00	10:00	22	25
	12:00	28	31
	13:00	33	35
	14:00	31	39
	15:00	34	44
8/30/00	10:00	18	10
	11:00	23	25
	12:00	29	31
	13:00	35	38
	14:00	43	53
	15:00	60	59